Asphalt Parking Lot Runoff Nutrient Characterization for Eight Sites in North Carolina, USA

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Abstract: The objectives of this study were to characterize asphalt parking lot runoff quality and determine factors influencing nutrient concentrations and loads. Event mean concentrations (EMCs) and loads were measured from eight asphalt parking lots in North Carolina using automated flow meters and rain gauges. The number of water quality samples collected varied from 11 to 26 per site. EMCs and loads were statistically analyzed for six nutrient forms: total nitrogen, total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, and ortho-phosphate. The mean EMCs (in mg/L) were 1.57, 1.19, 0.32, 0.36, 0.19 and 0.07, respectively. Nitrogen species' concentrations were slightly lower than those from highway runoff found in the literature; whereas, phosphorus EMCs were similar to those in highway runoff. Current load prediction models, generally based on highway or roadway nutrient concentrations, are therefore expected to over-estimate nitrogen loads from asphalt parking lots. Spring and summer presented the highest EMCs and loads, respectively. Significant seasonal differences in concentration ($p<0.05$) were found mainly between spring and the other three seasons, while loads in summer differed from those of fall and winter. In an attempt to determine the factors affecting EMCs and loads, Pearson correlation tests and multiple linear regression analyses were performed. Strong correlations were found among the variables of each group of factors referred to as climate, physical characteristics and surrounding land use. Rainfall depth, catchment area, the percentage of asphalt and natural surrounding land use were good predictors of nutrient concentrations and loads.

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Introduction

Impermeable surfaces resulting from urbanization increase runoff volume, limit groundwater recharge and often impair water quality. While pollution remediation systems are commonly implemented, storm water runoff continues to contribute to surface water pollution. The major sources of pollutants are dust fall, rainfall, soil erosion and the surrounding activities in the watershed. The latter include the use of pesticides, fertilizers, domestic chemicals as well as gas emissions, vehicle liquid leaks, pet wastes, animal and vegetation decomposition or direct disposal onto the drainage area (Pitt et al. 2004; Hall and Ellis 1985; Barnes et al. 2000; Rushton 2001). The limited infiltration capacity of asphalt surfaces enables pollutant buildup and prevents pollutants from being easily degraded. Thus, during a storm event, precipitation washes them into receiving waters. To minimize storm water pollution, the national pollutant discharge elimination system (NPDES) storm water permit requires departments of transportation, municipalities, counties and select industries to use best management practices (BMPs) to mitigate urban nonpoint source pollution.

Watershed load prediction models are commonly used by engineers to select and design BMPs. Several models of varying complexities exist. Simple storm water pollutant load models include those from the total maximum daily load (TMDL) program, in which load predictions are based on the simple method (Schueler 1987). The Tar-Pamlico river basin model (North Carolina), the PLOAD model (Oregon) and the spreadsheet tool for estimating pollutant load (STEPL, national) are some examples. Nutrient concentrations in runoff from impervious surfaces, which are usually based on highway or roadway nutrient concentrations, are key inputs in such models. Their appropriateness for use in asphalt parking lot watersheds is arguable. More complex models are generally based on equations describing pollutant build-up and wash-off processes (Chen and Adams 2006). A better understanding of the factors most affecting nutrient concentrations on asphalt parking lot areas could improve the accuracy of such models.

Several studies have assessed urban area, and particularly highway or roadway runoff quality, to characterize nutrient concentrations and loads (Barrett et al. 1995; Irish et al. 1995; Wu et al. 1998; Brezonik and Stadelmann 2002; Choe et al. 2002; Kayhanian et al. 2003, 2007). Characterization of asphalt parking lot runoff pollution is much less documented. Hope et al. (2004) studied three highly impervious sites in Arizona by carrying out simulated storm experiments after a very dry season. Large variations and substantially high values were observed for nitrate and ammonium concentrations. Results from a one-year study of two asphalt parking lots at the Florida Aquarium in Tampa are presented by Rushton (2001). Average event mean concentra-

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Table 1. General Characteristics of the Eight Monitored Sites

Site location	Site code	Monitoring period	No.[a] SE	DA[a]	PA[a]	SLU[a]	ARP[a]	Rfdepth[a]	Rfint[a]	ADP[a]
Charlotte	Char	Feb. 2004–March 2006	26	3,700	100	Commercial	100	24.5	3.6	162
Kinston	Kin1	June 2006–Feb. 2007	15	1,115	100	Commercial	100	17.2	1.5	87
	Kin2	July 2006–Feb. 2007	11	1,115	100	Commercial	100	17.6	2.6	105
Greensboro	Gre	Sept. 2002–August 2004	25	2,000	90	Commercial	90	36.6	2.4	166
Goldsboro	Gold	June 2003–Dec. 2004	14	615	100	Commercial	100	17.7	1.7	89
Louisburg	Lou1	May 2004–Nov. 2004	12	3,600	95	Natural area/park	99	36.0	2.7	151
	Lou2	June 2004–Feb. 2007	16	2,200	45	Natural area/park	88	34.9	1.2	139
Graham	Gra	Apr. 2006–March 2007	23	6,950	33	Residential	79	21.6	2.8	144

[a]SE=storm event; DA=drainage area (m^2); PA=percentage of asphalt (%); SLU=surrounding land use; ARP=asphalt runoff percentage (%); Rfdepth =average event rainfall depth (mm); Rfint=average rainfall intensity (mm/h); and ADP=antecedent dry period (h).

tions (EMCs) were nearly 0.55 mg/L for total nitrogen and 0.105 mg/L for total phosphorus.

The major factors found to affect runoff quality in highways or mixed land use watersheds were rainfall amount, intensity, drainage area (Brezonik and Stadelmann 2002), antecedent dry days, surrounding land use and average annual daily traffic (Kayhanian et al. 2003; Barrett et al. 1995; Driscoll et al. 1990). Asphalt parking lot surfaces occupy a substantial portion of urban watersheds, and they are assumed to show similar trends on nutrient accumulation and wash-off phenomena.

The objectives of this study were (1) to summarize monitoring data from asphalt parking lot runoff quality at eight sites in North Carolina; (2) to compute event mean concentrations and loads; (3) to determine major factors affecting EMCs and loads; and (4) to compare the data to the existing literature, particularly to discern differences between runoff from asphalt parking lots and highways.

Methods

Site Selection

Eight sites were included in the analysis. Each site met two criteria. First, a minimum of 10 sampled storm events was required, and secondly, the minimum percentage of runoff produced by the asphalt part of the watershed totaled 70% of the runoff generated. This percentage was chosen so that a majority of the pollutants came from the asphalt portion of the drainage area. The Natural Resources Service Curve Number (NRCS CN) methodology (SCS 1986; Mishra and Singh 2003) was used to calculate the runoff volumes generated by each land cover of the watersheds. As recently suggested (Woodward et al. 2003; Lim et al. 2006), a lower initial abstraction coefficient ($\lambda=0.05$) and associated modified curve numbers (CNs) were used.

Site Descriptions

The eight sites were located in six counties in North Carolina. Table 1 summarizes the general characteristics of the sites' drainage areas. The monitoring periods ranged from 6 (Louisburg 1 site, or Lou1) to 25 (Charlotte, or Char) months in the early 2000s. No data were collected for Louisburg 2 (Lou2) from December 2004 through October 2006 and for Goldsboro (Gold) from March to July 2004. Catchment areas ranged from 111.5 to 6,950 m^2. The major surrounding land use was commercial except for Lou1, Lou2 and Graham (Gra). The former two were principally surrounded by a park, whereas the latter was located in a residential and school area. Most of the drainage areas were nearly 100% asphalt except for sites Lou2 and Gra. In all cases, between 79% and 100% of the estimated total runoff volume was contributed by the asphalt portion of the watershed. Watershed size and percentage of impermeable cover were determined by either conducting a watershed survey with a total station (Lou1, Lou2, Gold, Gra, Gre, Kin1, and Kin2) or using aerial LIDAR data (Char). The percentage of asphalt (PerAsphalt) was determined by dividing the impermeable area (parking lot surface) by the total area. The highest average rainfall depths (Rfdepth, mm) during the monitoring periods were nearly 35 mm for Greensboro (Gre), Lou1 and Lou2. Char presented the highest average rainfall intensity (Rfint, mm/h) reaching 3.6 mm/h; whereas, for the other sites, Rfint varied from 1.18 and 2.8 mm/h. Finally, for each storm event, antecedent dry period (ADP, h) varied from 87 to 166 h.

Data Collection and Description

Composite samples were collected by automated samplers situated at the outlets of the parking lot drainage areas. In nearly all cases, the lab analyses provided EMCs that were analyzed for common nutrient forms: total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonia (NH_3-N), nitrate (NO_3-N), Orthophosphate (OPO_4-P) and total phosphorus (TP). Laboratory analytical procedures followed U.S. Environmental Protection Agency (USEPA 1993) Standard Methods (Table 2) except for the Greensboro and Louisburg sites which conformed to AWWA Standard Methods for Water and Wastewater Analysis (AWWA 1998). Rainfall and runoff measurements and estimations varied per site (Table 3). Runoff volumes were either measured on site or estimated by the NRCS CN ($\lambda=0.05$) methodology (Mishra and Singh 2003; Woodward et al. 2003; Lim et al. 2006). Automated samplers took samples at either a constant time-step (time-dependent), according to a constant amount of passed flow volume (flow-weighted), or each time a certain intensity of rainfall

Table 2. Analytical Methods Used by the Laboratories

Constituent	U.S. EPA	A.W.W.A.
TP	EPA 365.4	SM 4500-P F
OPO_4-P	EPA 365.1 or EPA 365.2	SM 4500-P F
TN	Calculated by TKN+NO_{3+2}-N	
TKN	EPA 351.2	SM 4500Norg B
NH_3-N	EPA 351.2 or EPA 350.1	SM 4500-NH_3 G
NO_3-N and NO_{2+3}-N	EPA 353.2	SM 4500-$NO^{3\ -}$E

Table 3. Rainfall Origin, Runoff Volume Determination, and Composite Sample Types

Site code	Raingauge location[a]	Runoff	Composite sample
Char	On site or USGS 351320080502645b[b]	Measured	Flow-weighted
Kin1	On site	Measured	Flow-weighted
Kin2	OPn site	Measured	Flow-weighted
Gre	On site	Estimated	Rainfall intensity dependent
Gold	Cherry Research Station[c]	Estimated	Time dependent
Lou1	On site	Estimated	Rainfall intensity dependent
Lou2	On site	Estimated	Rainfall intensity dependent
Gra	On site or USGS 02096500[d]	Estimated and measured	Time dependent and flow-weighted

[a]USGS numbers correspond to United States Geological Survey monitoring stations; whereas, Cherry Research Station was monitored by the Agricultural Research Service of North Carolina (ARS NC).

[b]2.4 km from Char site.

[c]8.4 km from Gold site.

[d]3.1 km from Gra site.

was measured (rainfall intensity dependent). On highly impervious surfaces, rainfall depth is highly correlated to runoff depth. Composite samples triggered by rainfall intensities are therefore a good approximation of flow-weighted composite samples for highly impermeable catchments. Rainfall duration (Rfdur, h), event average rainfall intensity and antecedent dry period were determined for each storm event. Event average rainfall intensity was calculated by dividing the total amount of rainfall of every storm by the corresponding rainfall duration.

Loads (L) were determined by multiplying every EMC by the corresponding runoff depth (Q)

$$L_{ij} = EMC_{ij} \times Q_j \tag{1}$$

where L_{ij}=load of pollutant i for storm event j (mg/m^2); EMC_{ij}=event mean concentration of pollutant i for storm event j (mg/L); and Q_j=total runoff depth of storm event j (mm).

Statistical Analyses

SAS 9.1.3 w/SPA™ software was used to perform statistical analyses. For each site individually and for all the eight sites, descriptive statistics were performed on EMCs and loads. All statistical analyses were conducted at an $\alpha=0.05$ significance level. The results were then compared to the existing literature on urban runoff quality. Seasonal concentrations and loads were compared by descriptive statistics and multi-comparison tests [Ryan-Einot-Gabriel-Welsch, "REGWQ," Day and Quinn (1989)]. Seasons were defined according to solstice and equinox days. For example, spring started on the spring equinox (March 23) and ended on the summer solstice (June 21). The effects of select factors on EMCs and loads were assessed. Factor statistical distributions were first assessed. Pearson correlation tests and variance inflation factors (VIF) were then performed in order to detect possible dependence among the predictive explanatory variables. VIF values exceeding 2.5 and strong statistically significant correlations were regarded as indicating multicollinearity. The corresponding factors were dropped from the regression models. Correlations among pollutant loads and concentrations with the predictors were then assessed. Multiple linear regression (MLR) models were developed to obtain standardized coefficients. Forward, backward and stepwise SAS procedures were first employed to select the independent factors that seemed to best describe constituent concentrations or loads. Then, other factors were removed until a predictive MLR model was determined. Its selection was based on several statistical runs simultaneously considering four main factors: (1) obtaining the highest number of significant factors; (2) high R-squared values; (3) verifying the assumption that residuals were normally distributed; and (4) verifying the assumption that residuals had constant variance. The third assumption was checked by observing cumulative probability plots and Cramer-von Mises tests. The fourth assumption was evaluated by examining residuals versus predictive value plots. Log-transforming the data helped verifying these assumptions.

Results and Discussion

Individual Site Water Quality Results

Table 4 shows average EMCs and loads for each monitored site. Mean TP concentrations ranged from 0.07 to 0.33 mg/L and mean TN concentrations varied from 1.13 to 2.19 mg/L. Compared to values found in the literature (Table 5), TP concentrations are comparable to published data on highway or roadway runoff; whereas, TN results are slightly lower. Lou1 and Lou2 sites had the highest means for TN, TKN and TP concentrations; whereas, the lowest concentrations for TN, TKN and TP were found at sites Kinston 1 (Kin1), Kinston 2 (Kin2) and Gra. This is consistent with the fact that Lou1 and Lou2 were not entirely impervious and were surrounded by a natural (park) land use. These sites may have received more nutrients than commercial sites probably due to the use of fertilizers or by plant material decomposition. Considering loads, the highest TN and TKN loads were measured in Char, Gre, Lou1 and Lou2 sites. These four sites were those which received the highest average rainfall depths during the monitoring period (Table 1). Rainfall appears to be a non-negligible source of nitrogen species. This trend is not as clear for phosphorus species. OPO_4-P and TP highest loads were found for Lou1; whereas, for the other sites, small loads with few differences were noted. These results do not support a strong link between phosphorus inputs and rainfall amounts. Furthermore, the highest concentrations for OPO_4-P were found at Lou1; whereas, Lou2, Gre and Kin2 had the lowest OPO_4-P concentrations. As noted previously, Lou2 also had a high value for TP average EMC. Therefore, the major form of phosphorus for Lou2 site runoff could be particulate-bounded phosphorus. Among the eight sites, NH_3-N and NO_3-N concentration and load variations were low.

Table 4. Average EMCs (mg/L) and Loads (mg/m^2) per Site

Site code and variable value		Constituent					
		TP	OPO_4-P	TN	TKN	NH_3-N	NO_3-N
Char							
	EMC	0.20	—	1.83	1.37	0.39	0.42
	Load	4.13	—	36.80	28.13	8.48	9.19
Kin1							
	EMC	0.10	0.09	1.13	0.46	0.26	0.36
	Load	0.78	0.70	8.12	3.28	1.96	2.77
Kin2							
	EMC	0.07	0.05	1.14	0.38	0.30	0.37
	Load	0.79	0.64	15.48	2.70	3.76	6.34
Gre							
	EMC	0.18	0.05	1.57	1.29	0.36	0.28
	Load	5.88	2.55	48.08	40.28	7.48	7.60
Gold							
	EMC	0.20	0.06	1.52	1.22	0.35	—
	Load	1.39	0.19	9.98	7.67	1.92	—
Lou1							
	EMC	0.33	0.20	1.84	1.48	0.27	0.36
	Load	9.07	4.99	47.01	34.39	3.57	12.67
Lou2							
	EMC	0.23	0.02	2.19	1.37	0.29	0.43
	Load	3.43	0.23	43.93	29.07	5.08	5.04
Gra							
	EMC	0.08	0.01	1.43	0.68	0.27	0.36
	Load	0.91	0.19	11.69	8.40	2.10	3.51

Descriptive Statistics for EMCs and Loads for the Set of the Eight Sites

Descriptive statistics for runoff quality of the eight sites combined are presented in Table 6. Concentrations and loads for some pollutants varied up to four orders of magnitude. TKN and, consequently, TN concentrations and loads presented the widest range of values. The ammonia mean concentration was 0.32 mg/L, and the mean load was 4.86 mg/m^2, accounting for only 21% of TKN mean load. Nitrate concentrations ranged between 0.02 and 3.00 mg/L and loads varied from 0.06 to 83.07 mg/m^2. It appears that organic nitrogen (ON) was the major form of nitrogen in asphalt parking lot runoff. No TP and OPO_4-P concentration was greater than 1.40 mg/L and medians were 0.12 and 0.04 mg/L, respectively. TP and OPO_4-P median loads were 1.48 mg/m^2 and 0.36 mg/m^2, respectively. Concentrations of TP, TN and TKN, were found to be log-normally distributed; whereas, all constituents had loads that were log-normally distributed. Van Buren et al. (1997) reported that parking lot runoff EMCs of TP, NH_3-N and TKN were log-normally distributed.

The first two studies in Table 5 relate specifically to parking lot runoff (Hope et al. 2004; Rushton 2001). NH_3-N and NO_3-N concentration results presented herein are similar to Rushton's results (2001) but are much lower than those found by Hope et al. (2004). This might be explained by the fact that the latter study was conducted after a dramatically long dry period enabling pollutants to accumulate. Like Rushton, this study was conducted in the eastern U.S. Overall, taking into account the results from highway, roadway and urban runoff, the concentrations from the eight sites monitored for this study were slightly lower than those found in the literature. The exceptions are a few values for TP (Barrett et al. 1995; Wu et al. 1996; Irish et al. 1995) and TKN (Driscoll et al. 1990). Only Rushton's results, also obtained from a parking lot study, were lower than those presented herein. Nevertheless, except for the nitrate results reported by Hope et al. (2004), the maximum differences did not exceed one order of magnitude. It therefore appears that highway runoff TN concentrations are higher than parking lot TN concentrations. Conclusions are less definitive for TP.

Similar to concentrations, loads found by Hope et al. (2004) for ammonia and nitrate were higher by one or two orders of magnitude than the loads calculated in this study (Table 7). Overall, most of the nutrient loads determined by previous studies were higher than the nutrient loads presented herein with the exception of a few values. However, load comparisons are only based on five studies.

The major factor differentiating highway and parking lot sites is the average daily traffic (ADT). Comparing highway runoff quality results from the literature to asphalt parking lot results presented in this paper, there is a difference between the concentrations and the loads from these two types of sites, particularly for TN concentrations. This confirms previous results showing that atmospheric deposition resulting from vehicle traffic may be rather localized (Barrett et al. 1995). Higher concentrations of nitrogen in highway runoff than in parking lot runoff could be attributed to higher rates of oxide nitrogen gas emissions, which translates to greater concentrations of nitrogen forms in rainfall. Phosphorus concentration interpretation is more problematic, but as shown previously, the results presented herein are not systematically lower than those of highway values found in previous studies. It was previously shown that rainfall and atmospheric

Table 5. Results of This Study and Previous Studies Average Concentrations (mg/L) in Urb, HW, or Asphalt PL Runoff

Reference	Type[a]	TP	OPO_4-P	TN	TKN	NH_3-N	NO_3-N
These 8 parking lots		0.21	0.07	1.63	1.24	0.32	0.36
Hope et al. (2004)	PL (3)	—	—	—	—	0.8	26.6
		—	—	—	—	9.6	14.2
		—	—	—	—	6.7	3.4
Rushton (2001)	PL (2)	0.106	0.044	0.556	—	0.133	0.273
		0.105	0.062	0.548	—	0.123	0.28
Barrett et al. (1995)	HW (3)	0.42	—	—	—	—	1.25
		0.13	—	—	—	—	0.96
		0.1	—	—	—	—	0.36
Wu et al. (1996)	HW (1)	0.14	0.10	—	0.88	0.22	—
Wu et al. (1998)	HW (3)	0.43	0.15	—	—	0.83	—
		0.52	0.30	—	—	0.67	—
		0.47	0.17	—	—	0.52	—
Kayhanian et al. (2003)	HW (83)	0.3	0.1	—	2	1.1	1.1
Kayhanian and Borroum (2000)	HW (10)	0.7	—	—	5.2	1.9	1.8
Kayhanian et al. (2007)	HW (34)	0.29	0.11	—	2.06	—	1.07
Irish et al. (1995)	HW (2)	0.41 (med)[b]	—	—	—	—	1 (med)[b]
		0.08 (med)[b]	—	—	—	—	0.73 (med)[b]
Brezonik and Stadelmann (2002)	Urb (68)	0.58	—	3.08	2.62	—	—
Choe et al. (2002)	Urb (6)	1.96	—	—	6.76	—	—
Driscoll et al. (1990)	HW (31)	—	0.16 (med)[a]	—	0.87 (med)[b]	—	—
USEPA (1983)	HW (3)	0.62 (Res)[c]	—	—	2.85 (Res)[c]	—	—
		0.29 (Com)[c]	—	—	1.50	—	—
		0.33 (med)[b]	—	—	1.50 (med)[b]	—	—

[a]Type is expressed as asphalt PL=parking lot; HW=highway, or Urb=urban sites. The additional number indicates the number of site for each study.
[b]med=median.
[c]Res and Com are average EMCs for residential and commercial sites, respectively.

deposition accounted for a large part of runoff loads for nitrogen and phosphorus species (Irish et al. 1995; Wu et al. 1998; Hope et al. 2004; Rushton 2001; Barrett et al. 1995; Pollman et al. 2002; Whitall and Paerl 2001). Through a multiple linear regression analysis, Kayhanian et al. (2003) found that higher annual ADT produced higher NO_3-N, TKN and TP concentrations from highway runoff. In a recent study (Kayhanian et al. 2007), similar conclusions were drawn except that annual ADT had a negative effect on OPO_4-P concentrations. Barrett et al. (1995) reported the highest concentrations of NO_3-N and TP occurred at the highest traffic site of their study. Driscoll et al. (1990) showed that the effect of ADT was not significant.

Concentrations used in load prediction models are generally based on highway or roadway runoff quality data. It therefore seems that these models could overestimate TN, and in some cases, TP load predictions from asphalt parking lot runoff. The Tar-Pamlico load prediction model (NC DENR 2003), commonly used by engineers in North Carolina to choose and design BMPs,

Table 6. Descriptive Statistics for EMCs (mg/L) and Loads (mg/m^2) for the Eight Sites

Constituent	N	Mean	Median	SD	Range
EMC					
TP	116	0.19	0.12	0.21	0.005–1.40
OPO_4–P	74	0.07	0.04	0.10	0.005–0.64
TN	143	1.57	1.31	1.16	0.100–7.30
TKN	115	1.19	0.97	0.98	0.05–5.70
NH_3–N	141	0.32	0.22	0.35	0.01–2.10
NO_3–N	110	0.36	0.30	0.34	0.02–3.00
Load					
TP	113	4.01	1.48	7.20	0.026–60.84
OPO_4–P	72	1.89	0.36	5.69	0.015–44.25
TN	140	28.17	14.40	38.48	0.32–201.73
TKN	112	25.00	12.16	35.37	0.22–177.00
NH_3–N	139	4.86	2.11	6.87	0.07–38.72
NO_3–N	110	6.44	3.08	9.95	0.06–83.07

Table 7. Results of This Study and Previous Studies Average Loads (mg/m^2) in Urban, Highway, Roadway, or Asphalt Parking Lot Runoff

Reference	TP	OPO_4-P	TN	TKN	NH_3-N	NO_3-N
These 8 parking lots	3.88	1.70	29.37	23.35	4.86	6.43
Hope et al. (2004)	—	—	—	—	11.5	156.3
	—	—	—	—	84.3	127.1
	—	—	—	—	57.1	28.7
Barrett et al. (1995)	48	—	—	—	—	142
	13	—	—	—	—	98
	1	—	—	—	—	4
Wu et al. (1998)	3.05	12	—	—	6.65	—
	7.85	4.56	—	—	8.81	—
	14.06	5.35	—	—	14.04	—
Brezonik and Stadelmann (2002)	1.9	—	10.3	9.6	—	—
Choe et al. (2002)	15	—	—	51.7	—	—

is based on TN and TP concentrations of 2.6 and 0.19 mg/L, respectively, for transportation catchments. A national model [STEPL model, Tetra Tech, Inc. (2006)] enables calculating loads for different kinds of watersheds by varying the annual rainfall amount but uses 3.0 and 0.5 mg/L for TN and TP concentrations, respectively, for all states. Other studies (NC DENR 2005) or models [PLOAD model, CH2M HILL (2006)] recommend the use of similar values. These TN concentration values are greater than those found in this study for eight parking lot sites; whereas, the TP values are similar (Tables 4 and 6). A larger dataset for asphalt parking lot runoff nutrient quality should be assembled to confirm these findings. However, TN concentrations at all eight sites are lower than those currently used in load prediction models.

Seasonal Variation

Spring had the highest median concentrations and largest ranges for all nutrient forms except OPO_4-P. For that particular species, summer presented the widest range of values. Median concentrations of OPO_4-P were similar among seasons, ranging from 0.02 to 0.05 mg/L. Rainfall depth, rainfall duration and antecedent dry period were lowest in spring. Less frequent and smaller storm events in spring may mean less dilution, and therefore, higher concentrations. The lowest median concentrations for OPO_4-P and NO_3-N occurred in summer; whereas, for all the other constituents, the lowest concentrations occurred in winter, but they were not very different from fall median values. Winter was the season showing the smallest range of concentrations. Multi comparison REGWQ tests ($\alpha=0.05$) showed that spring TN, TKN and NH_3-N concentrations were significantly different from summer, fall and winter concentrations. TN and TKN concentrations were also significantly different between summer and winter. No significant difference was found for OPO_4-P; whereas, spring TP concentrations were significantly different from those of winter.

When examining all loads, summer had the highest median loads and the largest ranges. Summer rainfall depth for the eight sites was the highest, further supporting the fact that rainfall could be a major source of nutrients. Winter had the smallest ranges of loads and showed the lowest load medians for all constituents apart from OPO_4-P and NO_3-N. These two species had the lowest median concentrations in spring and in fall, respectively. Finally, significant differences between summer and both fall and winter loads for TN, TKN and OPO_4-P were found. Spring and both fall and winter TKN loads were also significantly different. Summer TN loads were significantly different than those of spring.

The fact that higher pollutant loads and concentrations were observed in summer and spring bodes well for the use of biological storm water treatment systems. Storm water wetlands and bioretention cells, which both rely on biological activity for nutrient removal, have been shown to remove more pollution during the growing season, which includes spring, summer and most of fall in North Carolina (Hunt et al. 2006; Jing et al. 2001).

Correlation Analysis

For future modeling efforts to predict nutrient concentrations and loads from parking lots, predictive factors (or inputs) will be needed. The second portion of this analysis examined nine potential predictive factors of concentrations and loads for correlation and multiple linear regression analyses. Among the nine factors, four were related to the climate and five to watershed physical characteristics or the main characteristic of the surrounding neighborhood. Three factors were log-transformed to meet the residual normality assumption. Climatic factors were rainfall depth (lnRfdepth, mm), duration (lnRfdur, h), average rainfall intensity (lnRfint, mm/h) and antecedent dry period (ADP, h). Watershed physical characteristics were catchment area (CatArea, m^2) and the percentage of asphalt within the drainage area (PerAsphalt, %). Main surrounding activity corresponded to three different major land uses referred to as commercial (Com), residential (Res) or natural/park (Nat). Correlations were assessed among the nine predictive factors.

Correlations among the Predictive Factors

The three surrounding land uses (SLUs), Com, Res and Nat, were strongly correlated among themselves. In the dataset, only one of the three SLUs was assigned to each site as a continuous variable leading to colinearity among Com, Res and Nat. Among the three SLUs, the strongest correlations were found for Com and Res. In addition, variance inflation factor (VIF) values for Res were greater than 8. Therefore, only Nat was then included as part of the MLR models. The SLU factors were also correlated with the percentage of asphalt and the catchment area. Rainfall duration had a significant and strong correlation with two other rainfall variables, lnRfdepth (0.532) and lnRfint (−0.695). LnRfdur was not included as part of further MLR analyses. Rainfall depth was also correlated with antecedent dry period (0.233) and average rainfall intensity (0.238). The percentage of asphalt within the

Table 8. Pearson Correlation Coefficients for EMCs and Loads

Constituent	ln Rfdepth (mm)	ln Rfdur (h)	ADP (h)	ln Rfint (mm/h)	CatArea (m^2)	PerAsphalt (%)	SLU Com	SLU Res	SLU Nat
Ln(EMCs)[a]									
TP	−0.131	−0.161	−0.148	0.063	0.015	0.147	−0.062	−0.191[b]	0.210[b]
OPO_4−P	−0.136	−0.164	−0.079	0.046	−0.100	0.517[b]	0.036	−0.277[b]	0.106
TN	−0.272[b]	−0.213[b]	−0.024	0.013	0.147	−0.038	−0.086	−0.011	0.121
TKN	−0.226[b]	−0.133	−0.066	−0.045	0.039	0.149	0.049	−0.167	0.068
NH_3−N	−0.393[b]	−0.190[b]	0.003	−0.123	0.002	0.144	0.195[b]	−0.049	−0.190[b]
NO_3−N	−0.350[b]	−0.182	0.074	−0.093	0.098	0.041	0.054	0.118	−0.178
Ln(Loads)[a]									
TP	0.587[b]	0.190[b]	−0.043	0.274[b]	0.060	0.156	0.010	−0.218[b]	0.150
OPO_4−P	0.663[b]	0.222	−0.049	0.329[b]	0.038	0.373[b]	0.020	−0.202	0.085
TN	0.665[b]	0.330[b]	0.123	0.183[b]	−0.010	0.147	0.077	−0.272[b]	0.180[b]
TKN	0.590[b]	0.241[b]	0.023	0.222	−0.090	0.145[b]	0.079	−0.193[b]	0.055
NH_3−N	0.466[b]	0.287[b]	0.148	0.069	−0.094	0.288[b]	0.291[b]	−0.273[b]	−0.087
NO_3−N	0.601[b]	0.377[b]	0.272[b]	0.084	−0.118	0.247[b]	0.219[b]	−0.193[b]	−0.066

[a]Ln(EMCs) and Ln(Loads) are log-transformed concentrations (mg/L) and loads (mg/m^2), respectively.
[b]Coefficient are significantly different from zero ($\alpha = 0.05$).

watershed was strongly correlated with the catchment area (−0.654) which reflects that in this study the largest watersheds were the least impervious ones (Table 1).

Predictive Factor Correlations with EMCs and Loads

Correlations among runoff nutrient concentrations and loads and the predictive factors are shown in Table 8. The strongest correlations were negative and found between rainfall depth or duration and all concentrations. Only correlations between phosphorus forms and lnRfdepth were not significant ($\alpha = 0.05$). Similar results were found previously on a mixed land use watershed runoff study (Brezonik and Stadelmann 2002). LnRfint and ADP were not significantly correlated with concentrations. Positive correlations were found between every constituent concentration and catchment area, except for OPO_4-P, but they were not significant. Few significant correlations were found between concentrations and SLUs, with the correlations being both positive and negative. Two significant correlations were found between TP concentrations and SLUs. TP concentrations were negatively correlated to the residential SLU and positively correlated to the natural SLU. This could be associated with plant decomposition and the application of fertilizers in the surrounding recreation park in Louisburg (Lou2). For TP concentrations, Brezonik and Stadelmann (2002) showed a positive relationship with residential SLU.

When examining loads, results showed that rainfall depth followed by rainfall duration had the strongest positive correlations with all loads. Overall, ADP, lnRfint and PerAsphalt were also positively correlated with all loads, but they were not all significant. Because load is based upon runoff volume and concentration, positive correlation with rainfall depth is expected. Apart from the TN load, catchment area was both positively and negatively correlated with loads but correlations were not significant. Positive correlations were found between the commercial SLU and loads but fewer than half of the coefficients were significant. Results for residential SLU showed significant negative correlations with loads as was previously found by Brezonik and Stadelmann (2002). Keep in mind that these results only included one residential SLU site (Gra) and should consequently be confirmed by further research.

Multiple Linear Regression Analyses

MLR with Groups of Variables

Three groups of variables were created and tested as predictors to evaluate their global influence on nutrient models for concentrations and loads. The group named "climate" included lnRfdepth, lnRfdur, lnRfint and ADP. PerAsphalt and CatArea accounted for the "physical characteristics" group, and Res, Com and Nat belonged to the "SLU" group. It was shown that the collective contribution of climate variables was a significant predictor for most concentrations and all loads. Physical characteristics significantly predicted the concentrations of OPO_4-P, TN and TP and all loads except that of NO_3-N. SLU appeared to be a poor predictor, being significant only for OPO_4-P concentration prediction and NH_3-N, OPO_4-P and TN load predictions.

By isolating highly correlated factors, the following general model was tested

$$\text{Ln EMC}_i \text{ or Ln L}_i = \beta_1^* \ln \text{Rfdepth} + \beta_2^* \ln \text{Rfint} + \beta_3^* \text{ADP} + \beta_4^* \text{CatArea} + \beta_5^* \text{PerAsphalt} + \beta_6^* \text{Nat}$$

where Ln EMC_i and Ln L_i are, respectively, the log-transformed event mean concentration and load of constituent i.

β_i are the parameter coefficients (standardized values) computed by statistical models (in this case, SAS™) for constituent i.

MLR Results for Nutrient Concentrations

Table 9 presents the β_i coefficients obtained from the MLR analyses. For each nutrient concentration MLR model, between one (for NO_3-N) and four (for TP, OPO_4-P, and TKN) factors were statistically significant coefficients, indicating that some of the six factors used in the models are weak. However, some nonsignificant factors were added to meet the residual normality assumption or to increase the total number of significant factors in the models. R-squared values ranged between 0.133 and 0.489. The low R-squared values demonstrate that the models could be improved with the inclusion of other independent factors.

LnRfdepth had negative coefficients for all constituent concentrations. These coefficients were all significantly different from

Table 9. MLR Standardized Coefficients for EMC and Load Predictions

Constituent	ln Rfdepth (mm)	ln Rfint (mm/h)	ADP (h)	CatArea (m^2)	PerAsphalt (%)	Nat	R^2
Ln(EMCs)[a]							
TP	-0.185^b	—	-0.139	0.283^b	0.439^b	0.384^b	0.212
OPO_4-P	-0.241^b	0.153	-0.008	0.232^b	0.821^b	0.452^b	0.489
TN	-0.312^b	—	—	0.185^b	—	0.175^b	0.138
TKN	-0.235^b	—	—	0.240^b	0.328^b	0.234^b	0.133
NH_3-N	-0.385^b	—	—	0.195	0.251^b	—	0.188
$NO_3-N+0.02$	-0.330^b	—	—	—	0.008	-0.126	0.138
Ln(Loads)[a]							
TP	0.592^b	—	—	0.305^b	0.436^b	0.221^b	0.467
OPO_4-P	0.636^b	—	—	0.275^b	0.653^b	0.221^b	0.676
TN	0.653^b	—	—	0.223^b	0.378^b	0.151^b	0.515
TKN	0.619^b	—	—	0.278^b	0.334^b	—	0.439
NH_3-N	0.486^b	—	—	0.212^b	0.460^b	—	0.339
NO_3-N	0.582^b	—	0.180^b	—	0.265^b	-0.099	0.467

[a]Ln(EMCs) and Ln(Loads) are log-transformed concentrations (mg/L) and loads (mg/m^2), respectively.

[b]Coefficient are significantly different from zero ($\alpha=0.05$).

zero. Therefore, a decrease in the concentration would be expected for every increase in the rainfall depth of a storm event, supporting the idea of a dilution effect of the pollution associated with big storms. A similar tendency was previously found for other urban watersheds (Brezonik and Stadelmann 2002; Kayhanian et al. 2003, 2007). Low standardized negative coefficients were found for antecedent dry period predictor and phosphorus species. They were not significant. Some authors observed a positive relation between concentrations of NO_3-N, TP, TKN and antecedent dry period (Kayhanian et al. 2003, 2007); whereas, Brezonik and Stadelmann (2002) found a negative slope between dissolved phosphorus and the number of days since last event as presented herein.

Catchment area coefficients were significantly different from zero for TP, OPO_4-P, TN and TKN concentrations. Positive correlations with catchment area were found for all constituents except nitrate whose predictive model did not include the CatArea factor. This seemingly indicates that a greater drainage area leads to a higher concentration of these nutrients in the asphalt runoff. However, among these eight sites, higher proportions of grassed surfaces (where fertilizers are suspected to have been applied) were associated with the larger watersheds. Brezonik and Stadelmann (2002) analyzed data from mixed land use watersheds and found a significant negative coefficient only between TP concentrations and drainage area from a MLR analysis. From highway runoff studies, Kayhanian et al. (2003) found both positive (for NO_3-N and TP) and negative (for OPO_4-P) coefficients between concentrations and drainage area. In a recent study on highway storm water runoff quality, Kayhanian et al. (2007) showed that catchment area was a poor factor to predict nutrient EMCs. Positive and significantly different from zero coefficients were found for the percentage of asphalt within the watershed for TP, OPO_4-P, TKN and NH_3-N concentrations. This indicates that concentrations increase when increasing the percentage of impervious surface. Larger percentages of impermeable surfaces are assumed to be able to accumulate more pollutants but also to generate more runoff as infiltration is extremely reduced. With a higher percentage of asphalt, on the one hand, higher runoff volumes are produced and, on the other hand, more pollutants are accumulated. With both runoff volume and pollutant accumulation increasing, whether or not concentration levels increase with an increase in impervious area is not intuitive. The results of this study tend to show that the rate of pollutant buildup outweighs the rate of runoff production. In addition, coefficient values for percent of asphalt were often the highest ones among all standardized coefficients in the models. Therefore, the percentage of asphalt was a major predictor of nutrient concentrations.

MLR Results for Nutrient Loads

Load predictions by MLR analyses were also conducted. Generally, three to four factors were significant in the MLR models and R-squared values were higher than in EMC models, ranging from 0.339 to 0.676.

MLR analyses showed that the strongest coefficients were found for rainfall depth. They were significantly different from zero and positive for all loads. In addition to the diluting effect shown previously, higher rainfall amounts were associated with higher nutrient loads. This is probably partly due to a pollutant build-up and wash-off effect but could also be attributed to the fact that rainfall is generally a major source of nutrients in urban areas (Rushton 2001; Whitall and Paerl 2001; Pollman et al. 2002; Wu et al. 1998). Driscoll et al. (1990) showed that precipitation volume was the climate factor having the strongest effect on pollutant loading; whereas, rainfall intensity or duration was not significant. The nitrate load prediction model included ADP with a positive and significantly different from zero coefficient. Brezonik and Stadelmann (2002) also found a positive correlation between days since last event factor and both TKN and TN loads for mixed land use watersheds. This suggests that a longer dry period before a storm event could enable these pollutants to accumulate on asphalt impervious surfaces prior to being washed-off during the next storm. Generally, catchment area and the percentage of asphalt predictive factors were positive and significantly different from zero. Brezonik and Stadelmann (2002) found similar results for rainfall depth and drainage area coefficients to predict the loads of TP, TKN and TN. For the eight sites included in this study, the sites with the largest catchment areas were associated with natural and residential SLUs and had relatively lower fractions of impervious area. The loads are normalized per catchment areas; therefore, the effect of this predictor could reflect either the SLU or the percentage of impervious area effects.

Conclusions

Nitrogen species concentrations and loads determined from asphalt parking lot runoff from eight sites in North Carolina were lower than those found in previous studies on urban or highway runoff; whereas, phosphorus EMCs and loads were similar between parking lot and highway runoff. This indicates that traffic may be a key factor in nitrogen runoff input, but probably is not for phosphorus species. As a result, load prediction models, commonly based on highway or roadway nutrient concentrations, can therefore be expected to over-estimate nitrogen loads. Overall, seasonal differences were significant between spring and the other three seasons for concentrations and between summer and both fall and winter for loads. Spring and summer presented the highest values of concentrations and loads, respectively, for nearly all nutrient species.

Correlation and VIF analyses showed that some of the nine factors, lnRfdepth, lnRfdur, lnRfint, ADP, PerAsphalt, CatArea, Res, Com and Nat, were not independent. Hence, they were not all included in concentration or load prediction MLR models. It was highlighted that two groups of factors (climate and physical characteristics) best predicted concentrations and loads; whereas, the SLU variable effects were more difficult to determine. Overall, rainfall depth, catchment area, the percentage of asphalt and natural SLU were good predictors for nutrient EMCs and loads. From these eight sites, monitoring results supported the idea of a dilution effect and a pollutant build-up and wash-off tendency for nutrients on impervious surfaces. This phenomenon is partly attributed to higher rainfall depths, which could be a source of nutrients, and higher percentages of imperviousness. The impacts of residential and commercial SLUs on parking lot runoff quality were not determined; whereas, natural SLU was shown to increase both most of the nutrients' concentrations and loads. A wider assortment of surrounding land uses among the sites tested would probably have improved the assessment of SLU factor.

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Notation

The following symbols are used in this paper:

β_i = multiple linear regression coefficient;
C = concentration;
L = load;
Ln C_i = natural log-transformed concentration of constituent i;
Ln L_i = natural log-transformed load of constituent i;
lnRfdepth = natural log-transformed rainfall depth;
lnRfdur = natural log-transformed rainfall duration;
lnRfint = natural log-transformed average rainfall intensity;
MLR = multiple linear regression;
Nat = natural (park);
NH_3–N = ammonia nitrogen;
NO_3–N = nitrate nitrogen;
OPO_4–P = ortho-phosphate;
PerAsphalt = percentage of asphalt;
Res = residential;
Rfdepth = rainfall depth;
Rfdur = rainfall duration;
Rfint = average rainfall intensity;
ROdepth = runoff depth;
SLU = surrounding land use;
TKN = total Kjeldahl nitrogen;
TN = total nitrogen;
TP = total phosphorus;
α = level of significance; and
λ = initial abstraction coefficient.

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